AD-A220 946

OFFICE OF NAVAL RESEARCH

FINAL TECHNICAL REPORT

for

Contract N00014-86-K-0545

R&T Code 4134011

"Studies of Chemistry and Diffusion on Silicon and Gallium Arsenide Surfaces Using Laser-Induced Thermal Desorption"

Dr. Steven M. George
Department of Chemistry
Stanford University
Stanford, Calif. 94305

DTIC
ELECTE
APR 26 1990
S D
Co D

Reproduction in whole, or in part, is permitted for any purpose of the United States Government.

This document has been approved for public release and sales; its distribution is unlimited.

90 04 [illegible] 019

Outline - Final Technical Report

I. Overview

A. Principal Investigator

Dr. Steven M. George
Dept. of Chemistry
Stanford University
Stanford, Calif. 94305

Accesion For
NTIS CRA&I
DTIC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist Avail and/or Special
A-1

B. Cognizant ONR Scientific Officer

Dr. David L. Nelson / Dr. Mark Ross

C. Current Telephone Numbers

(415) 725-0270 (Office)
(415) 723-5918 (Lab)
(415) 723-1236 (Secretary)

D. Brief Description of Completed Project

Surface chemistry and surface diffusion play pivotal roles in semiconductor processing and must be understood as electronic device dimensions approach the submicron level. In this project, basic time-dependent processes on silicon surfaces were examined using laser induced thermal desorption (LITD) and Fourier transform infrared (FTIR) spectroscopy. These techniques provided direct, quantitative measurements of surface coverage in real-time. Using LITD and FTIR techniques, emphasis was on a microscopic understanding of semiconductor surface reaction kinetics.

The major areas addressed were the kinetics of fundamental semiconductor processing steps such as: surface oxidation and nitridation; epitaxial growth on surfaces; and surface etching. The Si(111)7x7 single crystal surface, as well as porous silicon surface, were used as the model semiconductor surfaces. These studies were conducted in UHV using Auger spectroscopy and LEED spectroscopy for surface analysis and characterization. The kinetic parameters that were determined by these LITD and FTIR studies are crucial for the understanding and modeling of semiconductor processing chemistry.

II. Significant Results from ONR Contract Support

This ONR sponsored research addressed the kinetics of fundamental surface reactions relevant to semiconductor processing chemistry. This section will highlight the research that has been published recently in refereed journals. Our more recent research on various chlorosilanes and chlorogermanes that are important in silicon and germanium epitaxy was initiated at the end of this ONR contract support and is still under investigation. This research will be discussed in future end-of-the-year reports for ONR N00014-90-J-1281.

A. Hydrogen Desorption Kinetics from Silicon Surfaces

Hydrogen plays a key role in silicon surface chemistry. Our initial LITD and FTIR studies explored the desorption kinetics of H_2 from Si(111)7x7 and porous silicon surfaces [1-3]. These investigations established the different thermal stabilities of monohydride and dihydride species. Moreover, these studies obtained kinetic parameters for monohydride and dihydride desorption. These kinetic parameters are useful for understanding the basic interaction of hydrogen with silicon surfaces and for modeling various CVD silicon processing steps.

B. Adsorption Kinetics of O_2 on Si(111)7x7

Oxygen forms an insulating oxide layer upon reaction with silicon surfaces. The details of oxygen adsorption and oxide growth in the submonolayer and monolayer regime have been debated actively. Our second major study addressed the initial growth of the silicon oxide layer on Si(111)7x7 [6,8]. We measured a

temperature-dependent sticking coefficient that decreased with temperature indicating a precursor adsorption mechanism. In addition, a temperature-dependent apparent saturation coverage was revealed that increased dramatically with surface temperature. These results should be useful for a complete understanding of silicon surface oxidation and models of silicon oxide growth in the thin film limit.

C. Laser-Induced Desorption of Silicon-Containing Surface Reaction Intermediates

During the examination of the LITD yield from Si(111)7x7 surfaces exposed to H_2O and NH_3, we discovered the presence of silicon-containing LITD species in the form of SiOH and $SiNH_2$ [4]. Additional examination of a hydrogen-saturated Si(111)7x7 surface revealed SiH_2 LITD products. Likewise, the Si(111)7x7 exposed to CH_3OH produced $SiOCH_3$ LITD species. These silicon-containing species were intriguing and suggested that laser desorption was able to desorb these surface reaction intermediates directly from the silicon surface. Subsequent FTIR investigations have confirmed that the silicon-containing LITD products correspond to silicon surface reaction intermediates. The ability of LITD to remove these reaction intermediates is extremely useful for kinetic studies of decomposition on silicon surfaces as discussed below.

D. Decomposition of H_2O on Si(111)7x7

Making use of the ability of LITD to desorb silicon-containing surface reaction intermediates, the decomposition of

H_2O was examined on Si(111)7x7 [5]. This study established the thermal stability of the SiOH species and monitored its decomposition between 400-600 K prior to H_2 desorption at 800 K and SiO desorption at 950 K. The decomposition kinetics for SiOH were self-poisoning at high coverages suggesting that the availability of free dangling-bond surface sites controls the reaction. Experiments with preadsorbed hydrogen also revealed surface passivation as hydrogen ties up free surface dangling bonds. These results are probably transferable to many decomposition reactions on silicon surfaces and should be especially useful in understanding the formation of insulating silicon oxide layers with H_2O oxidation.

E. Decomposition of NH_3 on Si(111)7x7

NH_3 is commonly employed to grow insulating silicon nitride layers. Like H_2O decomposition, NH_3 decomposes to yield hydrogen on the silicon surface. The availability of free surface sites may also be expected to control the surface reaction rates. By monitoring the $SiNH_2$ LITD species, the thermal stability and decomposition rates of the $SiNH_2$ surface reaction intermediate were studied on Si(111)7x7 [7]. The expected parallels between $SiNH_2$ and SiOH were established. In addition, a SiNH LITD species was observed that displayed different decomposition kinetics than $SiNH_2$ and suggested a partially step-wise decomposition of $SiNH_2$. Moreover, the effect of preadsorbed hydrogen was observed to passivate the Si(111)7x7 surface and reduce the NH_3 decomposition yield. These results should be useful for an understanding of silicon nitride film growth.

III. Graduate Students Working on Project

Five graduate students worked on various aspects of this ONR sponsored research:

1. Chi Mak. Entered Stanford 1984. Graduated 1988. NSF Fellow. Worked on LITD studies of H_2 desorption, O_2 adsorption and H_2O decomposition on Si(111)7x7. Postdoc work at U.C. Berkeley. Starts faculty position at USC, Fall, 1990.

2. Birgit Koehler. Entered Stanford 1985. Graduates Spring 1990. NSF Graduate Fellow. Worked on LITD studies of H_2 desorption, H_2O and NH_3 decomposition, $SiCl_4$ adsorption and desorption on Si(111)7x7. Starts postdoc at SRI, summer 1990.

3. Kim Gupta. Entered Stanford 1985. Graduates Fall 1990. Worked on FTIR studies of H_2 desorption and O_2 oxidation of porous silicon. Worked on LITD studies of O_2 adsorption, $SiCl_4$ adsorption and desorptionon Si(111)7x7. Accepted job with Intel-Santa Clara, Fall 1990.

4. Peter Coon. Entered Stanford 1987. Has worked on all LITD studies of adsorption, decomposition and desorption from Si(111)7x7. Third year student.

5. Anne Dillon. Entered Stanford 1988. Has worked on all new FTIR research on H_2O decomposition and NH_3 decomposition on porous silicon. Second year student.

IV. Publications Resulting from ONR Contract

1. Authors: P.Gupta, V.L. Colvin and S.M. George

   Title: "Hydrogen Desorption Kinetics from Monohydride and Dihydride Species on Silicon Surfaces"

   Journal: Physical Review B 37, 8234 (1988).

2. Authors: B.G. Koehler, C.H. Mak, D.A. Arthur and S.M. George

   Title: "Desorption Kinetics of Hydrogen from Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

   Journal: Journal of Chemical Physics 89, 1079, (1988).

3. Authors: P. Gupta, V.L. Colvin, J.L. Brand and S.M. George

   Title: "Hydrogen Desorption Kinetics from Silicon Surfaces Using Transmission FTIR" in Decomposition and Growth: Limits for Microelectronics

   Publisher: American Vacuum Society, edited by G.W. Rubloff

4. Authors: C.H. Mak, B.G. Koehler and S.M. George

   Title: "Laser-Induced Thermal Desorption of Silicon-Containing Surface Reaction Intermediates from Si(111)7x7"

   Journal: Surface Science 208, L42 (1989)

5. Authors: B.G. Koehler, C.H. Mak and S.M. George

   Title: "Decomposition of H_2O on Si(111)7x7 Studied Using Laser-Induced Thermal Desorption"

   Journal: Surface Science 221, 565 (1989)

6. Authors: P. Gupta, C.H. Mak, P.A. Coon and S.M. George

   Title: "Oxidation Kinetics of Si(111)7x7 in the Submonolayer Regime"

   Journal: Physical Review B40, 7739 (1989)

7. Authors: B.G. Koehler, P.A. Coon and S.M. George

   Title: "Decomposition of NH_3 on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

   Journal: Journal of Vacuum Science Technology B7, 1303 (1989)

8. Authors: S.M. George, P. Gupta, C.H. Mak and P.A. Coon

   Title: "Oxidation Kinetics of Silicon Surfaces: Reactive Sticking Coefficient, Apparent Saturation Coverage and Effect of Surface Hydrogen", in Chemical Prospectives of Microelectronic Materials"

   Journal: Material Research Society Symposium Proceedings 131, 169 (1989)

9. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

   Title: "Adsorption of Silicon Tetrachloride on Si(111)7x7", in Chemical Prospectives of Microelectronic Materials"

   Publisher: Material Research Society Symposium Proceedings 131, 197 (1989)

V. Manuscripts in Press or Preparation Resulting from ONR Contract

1. Authors: P. Gupta, C.H. Mak, P.A. Coon and S.M. George

   Title: "Kinetics of H_2O Adsorption on Si(111)7x7"

   Journal: Surface Science Letters (in preparation for submission

2. Authors: P. Gupta, A.S. Bracker, V.L. Colvin and S.M. George

   Title: "Oxidation Kinetics of Porous Silicon Studied Using Transmission FTIR"

   Journal: Journal of Electrochemical Society (in preparation for submission)

3. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

   Title: "Adsorption and Desorption Kinetics for $SiCl_4$ on Si(111)7x7"

   Journal: Journal of Chemical Physics (in press)

4. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

   Title: "Adsorption and Desorption Kinetics for Cl_2 on Si(111)7x7"

   Journal: (in preparation for submission)

5. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

   Title: "Adsorption and Desorption Kinetics for $SiCl_2H_2$ on Si(111)7x7"

   Journal: (in preparation for submission)

6. Authors: P.A. Coon, P. Gupta, B.G. Koehler and S.M. George

   Title: "Surface Hydride Species on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

   Journal: (in preparation for submission)

7. Authors: B.G. Koehler and S.M. George

   Title: "Laser Induced Thermal Desorption from Si(111)7x7: I. Numerical Calculations"

   Journal: (in preparation for submission)

8. Authors: P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

   Title: "Laser Induced Thermal Desorption from Si(111)7x7: II. Hydrogen Isothermal Desorption Kinetics"

   Journal: (in preparation for submission)

9. Authors: P. Gupta, A.C. Dillon, A.S. Bracker and S.M. George

   Title: "Decomposition of H_2O on Silicon Surfaces Studied Using Transmission FTIR"

   Journal: (in preparation for submission)

10. Authors: A.C. Dillon, P. Gupta, A.S. Bracker and S.M. George

    Title: "Decomposition of NH_3 on Silicon Surfaces Studied Using Transmission FTIR"

    Journal: (in preparation for submission)

11. Authors: S.M. George, P. Gupta, B.G. Koehler, C.H. Mak and P.A. Coon

    Title: "Laser Induced Thermal Desorption Studies of Reaction Kinetics on Si(111)7x7"

    Journal: Proceedings of MicroProcess '89 Japan Journal of Applied Physics (1990)

12. Authors: S.M. George, P. Gupta, B.G. Koehler, P.A. Coon, A.C. Dillon and C.H. Mak

    Title: "Silicon Surface Kinetics Studied Using Laser Induced Thermal Desorption"

    Journal: Laser Photoinization and Desorption Surface Analysis Techniques, SPIE Conference Proceedings, (SPIE, Bellingham, WA., 1990)

13. Authors: S.M. George, P. Gupta, B.G. Koehler, P.A. Coon, A.C. Dillon and C.H. Mak

Title: "Optical Probes of Silicon Surface Chemistry"

Journal: Proceedings of Sixth International Symposium on Silicon Materials Science and Technology, Journal of Electrochemical Society

VI. Invited Talks on Supported Work

1. "Diffusion and Desorption of Hydrogen on Surfaces"

   Xerox Palo Alto Research Center
   Electronics Materials Laboratory
   Palo Alto, Calif.
   June 19, 1987

2. "Diffusion and Desorption of Hydrogen on Surfaces"

   Signetics Phillips Research Center
   Sunnyvale, Calif.
   June 23, 1987

3. "Oxidation Kinetics of Silicon Surfaces
   in the Submonolayer Regime"

   Intel Corporation
   Santa Clara, Calif.
   April 26, 1988

4. "Reaction Kinetics on Si(111) 7x7 Studied Using Laser
   Induced Thermal Desorption"

   Xerox Palo Alto Research Center
   Electronics Materials Laboratory
   Palo Alto, Calif.
   Sept. 9, 1988

5. "Reaction Kinetics on Silicon Surfaces"

   Dept. of Chemistry
   Massachusetts Inst. of Technology
   Cambridge, Mass.
   Sept. 13, 1988

6. "Reaction Kinetics on Silicon Surfaces"

   Hewlett-Packard Research Center
   Palo Alto, Calif.
   Oct. 18, 1988

7. "Oxidation Kinetics of Silicon Surfaces"

   Symposium on Chemical Prospectives in Microelectronics
   Materials Research Society Fall Meeting
   Boston, Mass.
   Dec. 1, 1988

8. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
California Institute of Technology
Pasadena, Calif.
January 24, 1989

9. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
University of California at San Diego
La Jolla, Calif.
January 31, 1989

10. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
University of Texas at Austin
Austin, Texas
Feb. 23, 1989

11. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Department of Chemistry
Texas A & M University
College Station, Texas
Feb. 24, 1989

12. "Oxidation Kinetics of Silicon Surfaces"

Topical Meeting on Microphysics of Surfaces, Beams and Adsorbates
Salt Lake City, Utah
February 27, 1989

13. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

Dept. of Chemistry
Princeton University
Princeton, NJ
March 15, 1989

14. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

    Dept. of Chemistry
    University of Pennsylvania
    Philadelphia, Penn.
    March 16, 1989

15. "Reaction Kinetics on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

    ATT Bell Laboratories
    Murray Hill, NJ
    March 17, 1989

16. "Studies of Reaction Kinetics on Silicon Surfaces Using FTIR"

    Stanford Materials Research Forum
    Dept. of Materials Science and Engineering
    Stanford University
    Stanford, CA
    May 5, 1989

17. "Laser Induced Thermal Desorption Studies of Reaction Kinetics on Si(111) 7x7"

    International MicroProcess Conference 1989
    Japan Society of Applied Physics
    Kobe, Japan
    July 4, 1989

18. "Reaction Kinetics on Si(111): 7x7 Surfaces Studied Using Laser-Induced Thermal Desorption"

    Condensed Matter Seminar
    Univ. of California at Berkeley
    Berkeley, Calif.
    September 20, 1989

19. "Surface Kinetics Studies Using Laser-Induced Thermal Desorption"

    Symposium on Laser Photoionization and Desorption
    Surface Analysis Techniques
    SPIE National Meeting
    Los Angeles, Calif.
    January 18, 1990

20. "Reaction Kinetics on Si(111)7x7 Studied Using Laser-Induced Thermal Desorption"

Gordon Research Conference on The Chemistry of Electronic Materials
Ventura, Calif.
March 1, 1990

VII. Contributed Talks on Supported Work

1. "Transmission FTIR Studies of Porous Silicon"

   P. Gupta, V.L. Colvin and S.M. George

   Am. Chem. Soc. Natl. Meeting
   Denver, Colorado
   April 10, 1987

2. "Hydrogen Desorption Kinetics from Mono and Dihydride Species on Silicon Surfaces Using Transmission FTIR"

   P. Gupta, V.L. Colvin, J.L. Brand and S.M. George

   Am. Vac. Soc. Natl. Meeting
   Anaheim, Calif.
   Nov. 3, 1987

3. "Oxidation Kinetics of Silicon Surfaces in the Submonolayer Regime"

   P. Gupta, C.H. Mak, P.A. Coon and S.M. George

   ACS Symposium on "General Papers in Catalysis"
   Natl. Meeting of the American Chemical Society
   Los Angeles, Calif.
   Sept. 28, 1988

4. "Oxidation Kinetics of Silicon Surfaces in the Submonolayer Regime"

   P. Gupta, C.H. Mak, P.A. Coon and S.M. George

   Pacific Conference on Chemistry and Spectroscopy
   San Francisco, Calif.
   Oct. 26, 1988

5. "Decomposition of NH_3 on Si(111)7x7 Studied Using Laser Induced Thermal Desorption"

   B.G. Koehler, P.A. Coon and S.M. George

   Topical Meeting on Microphysics of Surfaces, Beams and Adsorbates
   Salt Lake City, Utah
   March 1, 1989

6. "Decomposition of NH_3 on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, P.A. Coon, and S.M. George

Northern Calif. Am. Vacuum Society Meeting
Stanford Linear Accelerator Center
Stanford, Calif.
June 1, 1989

7. "Decomposition of NH_3 on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, P.A. Coon, and S.M. George

Sixty-third Colloid and Surface Science Symposium
Sponsored by the American Chemical Society
University of Washington
Seattle, Wash.
June 21, 1989

8. "Adsorption and Desorption of Si Cl_4 on Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler, and S.M. George

Sixty-third Colloid and Surface Science Symposium
Sponsored by the American Chemical Society
University of Washington
Seattle, Washington
June 21, 1989

9. "Decomposition of NH_3 and H_2O on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, P.A. Coon, C.H. Mak and S.M. George

Gordon Research Conference on Inorganic Thin Films and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989

10. "Laser Induced Thermal Desorption for Studies of Surface Reaction Kinetics"

S.M. George, B.G. Koehler, C.H. Mak, P. Gupta and P.A. Coon

5th Interdisciplinary Laser Science Conference
Stanford University
Stanford, Calif.
August 30, 1989

11. "Laser Heating and Laser-Induced Desorption: Experimental and Theoretical Results for Silicon Surfaces"

B.G. Koehler, P. Gupta, P.A. Coon and S.M. George

5th Interdisciplinary Laser Science Conference
Stanford University
Stanford, Calif.
August 30, 1989

12. "Decomposition of NH_3 on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, P.A. Coon, P. Gupta and S.M. George

Am. Vac. Soc. Natl. Meeting
Boston, Mass.
October 24, 1989

13. "Adsorption and Desorption Kinetics for $SiCl_4$ on Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

Am. Vac. Soc. Natl. Meeting
Boston, Mass.
October 26, 1989

14. "Oxidation Kinetics of Si(111) 7x7 in the Submonolayer Regime"

S.M. George, P. Gupta, C.H. Mak and P.A. Coon

Am. Inst. Chem. Eng. 1989 Annual Meeting
Symposium on Kinetics and Mechanisms in
Electronics Materials Processing
San Francisco, Calif.
Nov. 8, 1989

15. "Adsorption and Desorption Kinetics for $SiCl_4$ on Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

Am. Inst. Chem. Eng. 1989 Annual Meeting
Symposium on Kinetics and Mechanisms in
Electronics Materials Processing
San Francisco, Calif.
Nov. 9, 1989

16. "Kinetics of H_2O Adsorption and Decompostion on Si(111) 7x7"

B.G. Koehler, P.A. Coon, P. Gupta and S.M. George

Am. Inst. Chem. Eng. 1989 Annual Meeting
Symposium on Kinetics and Mechanisms in
Electronics Materials Processing
San Francisco, Calif.
Nov. 9, 1989

VIII. Contributed Posters on Supported Work

1. "Porous Silicon: Chemical and Physical Characterization"

   P. Gupta and S.M. George

   Gordon Research Conf. on the Chemistry of
   Electronic Materials
   St. Paul's Academy, Concord, New Hampshire
   August 20, 1986

2. "Transmission FTIR Spectroscopy on Porous Silicon"

   P. Gupta and S.M. George

   Western Spectroscopy Association Annual Conf.
   Asilomar, Calif.
   Jan. 29, 1987

3. "Studies of Adsorbates on Porous Silicon Using
   Transmission FTIR Spectroscopy"

   P. Gupta, J.L. Brand and S.M. George

   Northern Calif. Am. Vac. Soc. Meeting
   IBM Almaden Research Center
   San Jose, Calif.
   Feb. 25, 1987

4. "Desorption Kinetics of Hydrogen from Silicon
   Surfaces Using Transmission FTIR"

   P. Gupta, V.L. Colvin and S.M. George

   Gordon Research Conf. on the Dynamics of Gas-
   Surface Interactions
   Proctor Academy, Andover, New Hampshire
   Aug. 13, 1987

5. "Desorption Kinetics of Hydrogen From Si(111)7x7
   Measured Using Laser-Induced Thermal Desorption"

   B.G. Koehler, C.H. Mak, D.A. Arthur and S.M. George

   Gordon Research Conf. on the Chemistry of Thin Films
   Colby-Sawyer College
   New London, New Hampshire
   Aug. 12, 1987

6. "Hydrogen Desorption Kinetics and Oxygen Reaction Kinetics on Silicon Surfaces"

P. Gupta, V.L. Colvin and S.M. George

Northern Calif. Am. Vac. Soc. Meeting
Sandia Natl. Lab.
Livermore, Calif.
Dec. 9, 1987

7. "Hydrogen Desorption Kinetics from Si(111)7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, C.H. Mak, D.A. Arthur, P.A. Coon and S.M. George

Northern Calif. Am. Vac. Soc. Meeting
Sandia Natl. Lab.
Livermore, Calif.
Dec. 9, 1987

8. "Initial Oxygen Reactions Kinetics on Silicon Surfaces"

P. Gupta, V. Colvin and S.M. George

Gordon Research Conf. on Chemistry of Electronic Materials
Ventura, Calif.
March 7-11, 1988

9. "Desorption Kinetics of Hydrogen and Deuterium From Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, C.H. Mak, D.A. Arthur, P.A. Coon, and S.M. George

Gordon Research Conf. on Chemistry of Electronic Materials
Ventura, Calif.
March 7-11, 1988

10. "The Effects of Decomposition Products on the Reaction of Water with Si(111) 7x7"

B.G. Koehler, C.H. Mak, S.M. George

Gordon Research Conf. on Chemistry of Electronic Materials
Ventura, Calif.
March 7-11, 1988

11. "Initial Oxygen Reaction Kinetics on Silicon Surfaces"

P. Gupta, V.L. Colvin and S.M. George

Gordon Research Conf. on Chemistry of
Electronic Materials
Ventura, Calif.
March 7-11, 1988

12. "Desorption Kinetics of Hydrogen and Deuterium from Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, C.H. Mak, D.A. Arthur, P.A. Coon and S.M. George

Gordon Research Conf. on Chemistry of
Electronic Materials
Ventura, Calif.
March 7-11, 1988

13. "The Effects of Decomposition Products of the Reaction of Water with Si(111) 7x7"

B.G. Koehler, C.H. Mak, S.M. George

Gordon Research Conf. on Chemistry of
Electronic Materials
Ventura, Calif.
March 7-11, 1988

14. "Laser-Induced Thermal Desorption of Silicon-Containing Intermediates from Si(111) 7x7"

C.H. Mak, B.G. Koehler and S.M. George

Gordon Research Conf. on Chemistry of Electronic Materials
Ventura, Calif.
March 7-11, 1988

15. "Oxidation Kinetics of Silicon Surfaces in the Submonolayer Regime"

P. Gupta, C.H. Mak, P.A. Coon, and S.M. George

Northern Calif. Am. Vacuum Society Meeting
IBM Almaden Research Center
San Jose, Calif.
June 3, 1988

16. "The Decomposition of H20 on Si(111)7x7: Effect of Preadsorbed Hydrogen and Observation of Surface Intermediates"

B.G. Koehler, C.H. Mak, and S.M. George

Northern Calif. Am. Vacuum Society Meeting
IBM Almaden Research Center
San Jose, Calif.
June 3, 1988

17. "Adsorption/Desorption Kinetics of $SiCl_4$ on Si(111) 7X7"

P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

Symposium on Chemical Prospectives in Microelectronics
Materials Research Society Fall Meeting
Boston, Mass.
Dec. 1, 1988

18. "Decomposition of H_20 on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption"

B.G. Koehler, P.A. Coon, C.H. Mak, and S.M. George

Northern Calif. Am. Vacuum Society Meeting
Stanford Linear Accelerator Center
Stanford, Calif.
June 1, 1989

19. "Adsorption and Desorption Kinetics for $SiCl_4$ on Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler and S.M. George

Northern Calif. Am. Vacuum Society Meeting
Stanford Linear Accelerator Center
Stanford, Calif.
June 1, 1989

20. "The Decomposition of NH_3 on Si(111) 7x7 Studied Using Laser-Induced Thermal Desorption.

B.G. Koehler, P.A. Coon, and S.M. George

Gordon Research Conference on Inorganic Thin Films and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989

21. "Kinetics of H_2O Adsorption and Decomposition on Si(111) 7x7.

B.G. Koehler, P. Gupta, C.H. Mak, P.A. Coon, and S.M. George

Gordon Research Conference on Inorganic Thin Films and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989

22. "Adsorption and Desorption of $SiCl_4$ on Si(111) 7x7"

P. Gupta, P.A. Coon, B.G. Koehler, and S.M. George

Gordon Research Conference on Inorganic Thin Films and Interfaces
Plymouth Academy
Plymouth, New Hampshire
July 5, 1989

23. "Oxidation Kinetics of Silicon Surfaces in the Submonolayer Regime"

P. Gupta, C.H. Mak, P.A. Coon and S.M. George

Am. Vac. Soc. Natl. Meeting
Boston, Mass.
October 26, 1989

24. "FTIR Studies of H_2O and NH_3 Decomposition on Silicon Surfaces"

A.C. Dillon, P. Gupta, A.S. Bracker, M.B. Robinson and S.M. George

Western Spectroscopy Association
37th Annual Conference
Asilomar Conference Center
Pacific Grove, Calif.
January 24-26, 1990

25. "Silicon Hydride Species on Si(111)7x7 Studies using Laser-Induced Thermal Desorption"

P.A. Coon, P. Gupta, B.G. Koehler, and S.M. George

Gordon Research Conference on The Chemistry of Electronic Materials
Ventura, Calif.
March 1, 1990

26. "FTIR Studies of NH_3 Decomposition on Silicon Surfaces"

A.C. Dillon, P. Gupta, A.S. Bracker and S.M. George

Gordon Research Conference on The Chemistry of Electronic Materials
Ventura, Calif.
March 1, 1990

27. "Reactions of Chlorosilanes on Si(111)7x7 Studied Using Laser-Induced Thermal Desorption"

P.Gupta, P.A. Coon, B.G. Koehler, and S.M. George

Gordon Research Conference on The Chemistry of Electronic Materials
Ventura, Calif.
March 1, 1990

28. "FTIR Studies of H_2O Decomposition on Silidon Surfaces"

P. Gupta, A.C. Dillon, A.S. Bracker, M.B. Robinson and S.M. George

Gordon Research Conference on The Chemistry of Electronic Materials
Ventura, Calif.
March 1, 1990

29. "Experimental and Theoretical Studies of H_2 Laser-Induced Thermal Desorption from Si(111)7x7"

B.G. Koehler, P.A. Coon, P. Gupta and S.M. George

Gordon Research Conference on The Chemistry of Electronic Materials
Ventura, Calif.
March 1, 1990